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(54) METHOD OF DETERMINING THE POSITION OF A MEDICAL INSTRUMENT

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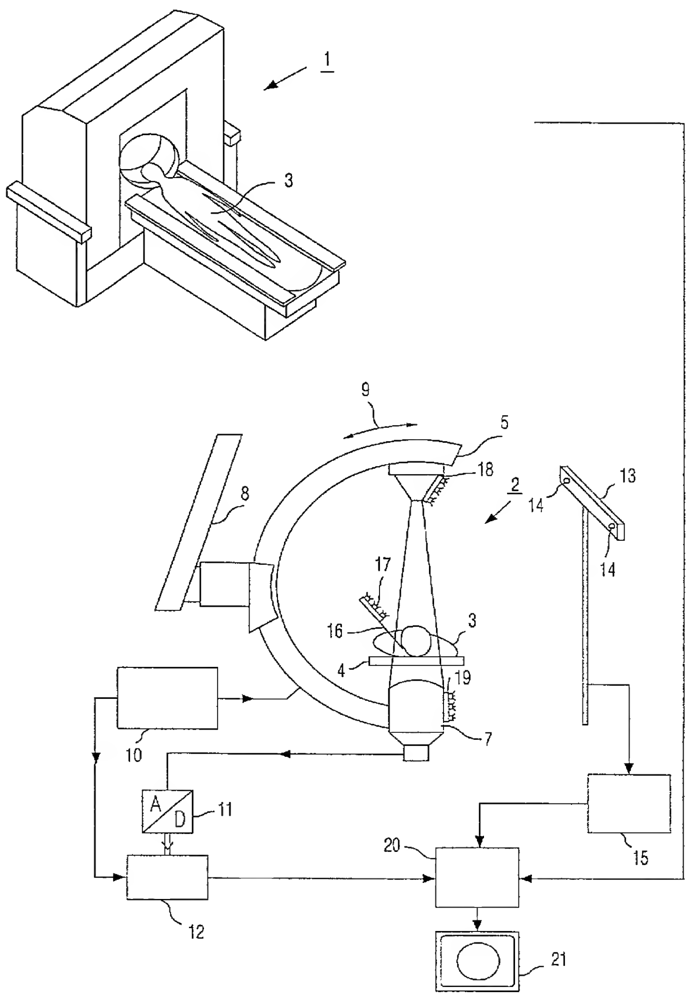
(57) **ABSTRACT**

The invention relates to a method of and a device for determining the position of a medical instrument **(13)**, partly introduced into an object to be examined, in a three-dimensional image data set (CT) of the object to be examined. In order to achieve an as high as possible accuracy of the position determination on the one hand and to minimize the expenditure required on the other hand, notably to save intricate registration steps prior to an intervention, the invention proposes to acquire, simultaneously with the acquisition of X-ray image (I_r), their spatial positions and the spatial position of a medical instrument **(6)** used, followed by determination of the spatial correlation between an X-ray image (I_r) and a three-dimensional image data set (CT), said correlation being used to transform the spatial position of the medical instrument **(16)** into a position relative to the three-dimensional image data set (CT). This enables the formation of images containing image information acquired pre-operatively as well as intra-operatively, and also the reproduction of the instantaneous position of the medical instrument in said images.



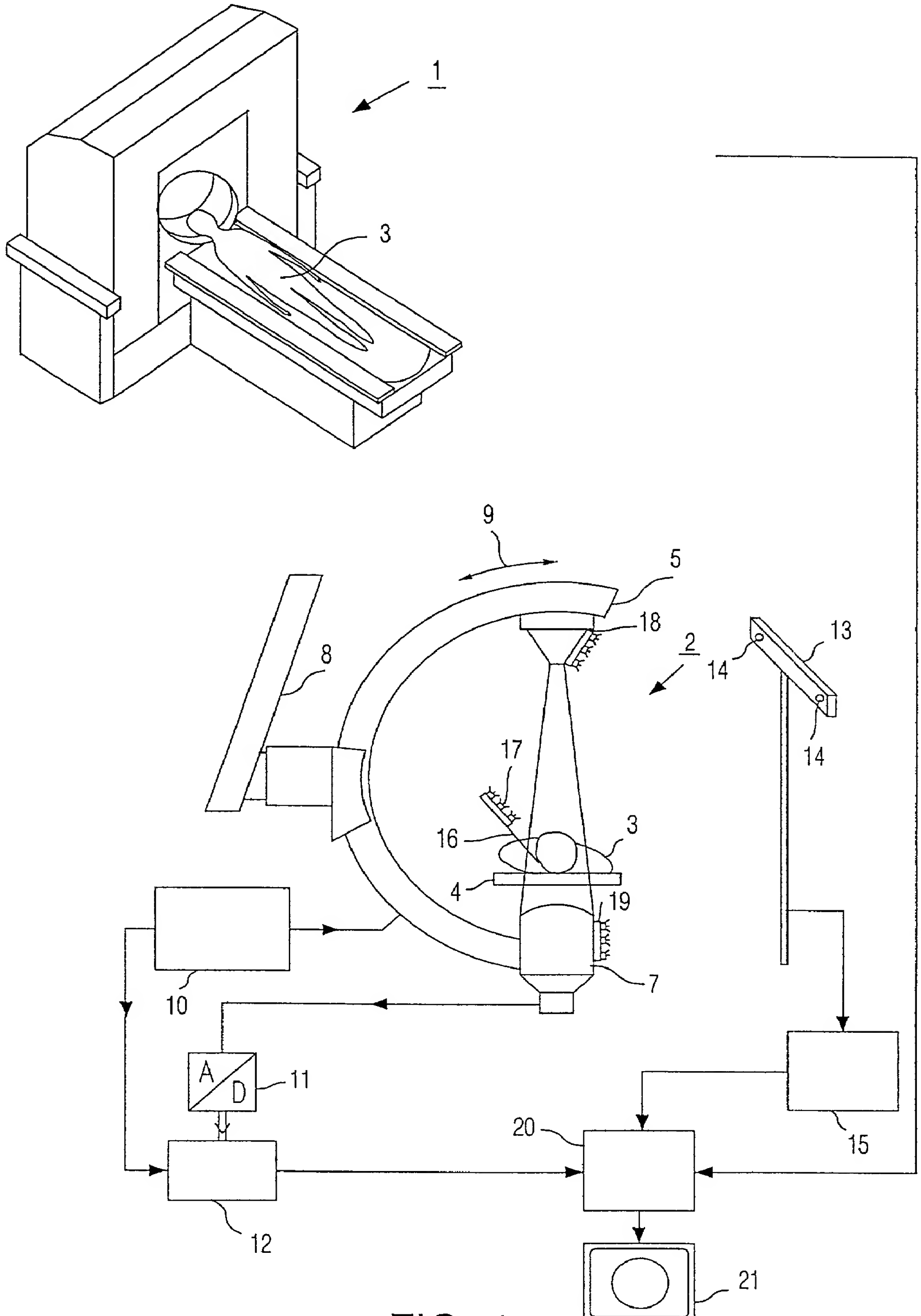
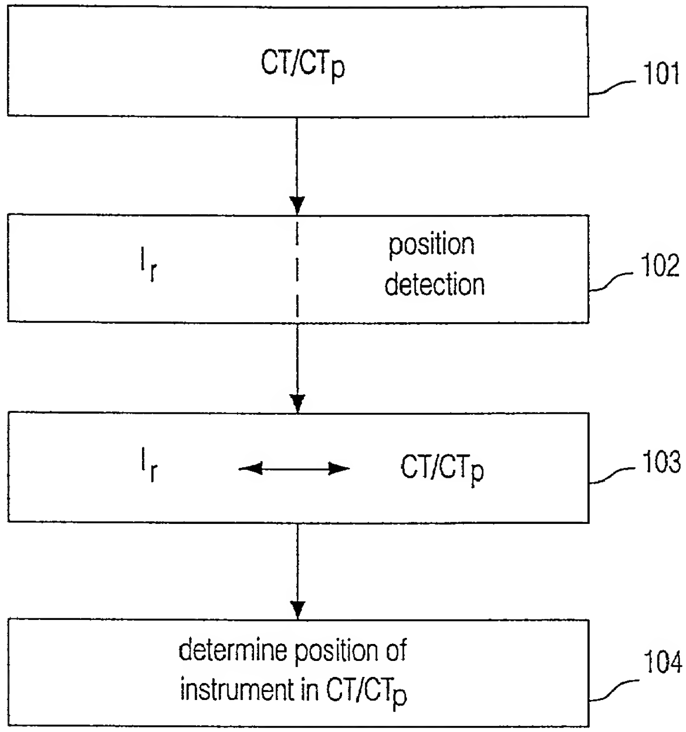
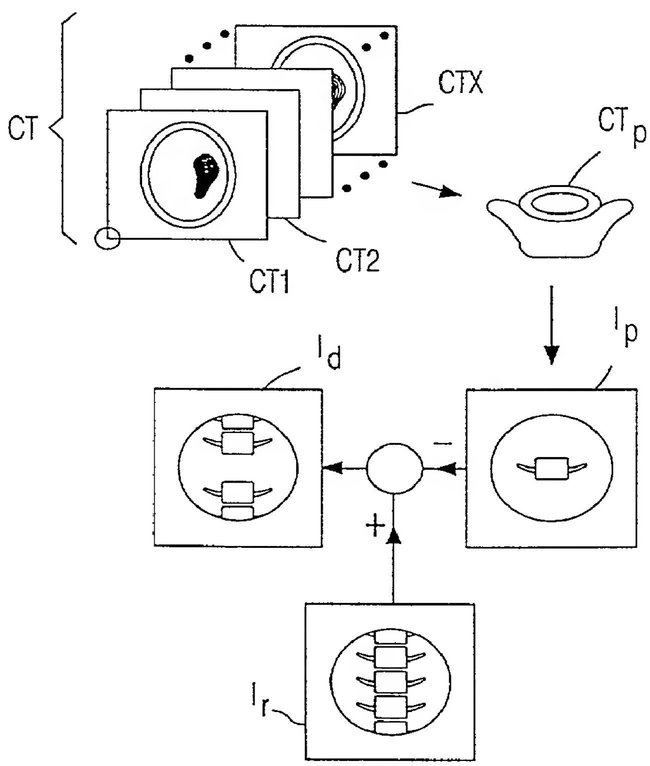


FIG. 1



CT/CTp
101
Ir
position detection
102
Ir
CT/CTp
103
determine position of instrument in CT/CTp
104

FIG. 2



CT
CTX
CTp
CT1
CT2
Id
Ip
−
+
Ir

FIG. 3

METHOD OF DETERMINING THE POSITION OF A MEDICAL INSTRUMENT

[0001] The invention relates to a method of determining the position of a medical instrument, partly introduced into an object to be examined, in a three-dimensional image data set of the object to be examined, and also relates to a device for carrying out such a method.

[0002] A method of and a device for determining the position of a medical instrument in a two-dimensional image data set are known from EP 857 461 A2. Therein, X-ray images of the examination zone of an object to be examined, for example a patient, are acquired intra-operatively by means of a C-arm X-ray device, while the position of the object to be examined, or the patient table, and of the medical instrument relative to the X-ray device is measured at the same time by means of an optical position measuring device. The position of the medical instrument can subsequently be transformed into a position relative to one or more of the X-ray images acquired, so that the respective instantaneous position can always be reproduced in one or more X-ray images. A method of this kind can serve as a navigational tool for the physician during the treatment of a patient. However, it has the drawback that no intra-operative three-dimensional image information is available for the navigation. Granted, an intervention can be planned on the basis of a pre-operative three-dimensional data set, but only two-dimensional X-ray images can be acquired intra-operatively and the position of the medical instrument can be determined and indicated only in such intra-operatively acquired two-dimensional X-ray images.

[0003] Granted, methods are known in which the position of a medical instrument is intra-operatively determined so as to be transformed into a position relative to a preoperatively acquired three-dimensional image data set. However, during the acquisition of the three-dimensional image data set the patient must be provided pre-operatively with special markers which are also reproduced in the three-dimensional image data set and are approached by a special pointer directly before the operation so as to determine their positions in space. An intra-operatively measured spatial position of a medical instrument can then be transformed into a position relative to the three-dimensional image data set by utilizing the positions of such markers which are thus known in spatial co-ordinates and in 3D image co-ordinates. Such methods, however, have the drawback that no instantaneous image information concerning the anatomy of the patient is used whereas during the intervention the anatomy regularly changes relative to the state of the anatomy during the pre-operative acquisition of the 3D image data set.

[0004] Therefore, it is an object of the invention to provide a method of determining the position of a medical instrument, partly introduced into an object to be examined, in a three-dimensional image data set of the object to be examined that avoids the above-mentioned drawbacks and enables notably a high accuracy to be achieved at an as small as possible expenditure. Moreover, it is also an object to provide a device which is suitable for carrying out such a method.

[0005] These objects are achieved by means of a method as disclosed in claim **1** and a device as disclosed in claim **9**.

[0006] The invention is based on the recognition of the fact that an intra-operative two-dimensional X-ray image can be advantageously used to transform the intra-operatively measured position of the medical instrument into a position relative to a three-dimensional image data set which will usually have been pre-operatively acquired. According to the invention, to this end not only the position of the medical instrument but the position in space of the X-ray image is measured intra-operatively. Using a suitable registration method, the spatial correlation between this X-ray image and the three-dimensional image data set is subsequently determined, thus yielding quasi the spatial position of the three-dimensional image data set. This knowledge enables a simple determination of the position of the medical instrument relative to the three-dimensional image data set because the spatial position of the medical instrument has been acquired directly before that. The invention thus enables a simple determination of the position of a medical instrument in a three-dimensional image data set without it being necessary to provide the patient during the acquisition of the image data set with special markers that are to be reproduced and must be registered again immediately before the operation. Moreover, intra-operatively acquired image data providing exact information concerning the anatomy of the patient are processed, so that the accuracy of the determination of the position is enhanced.

[0007] The advantageous version disclosed in claim **2** utilizes known means for determining the spatial position of the X-ray image; such means can also be used to determine the spatial position of the medical instrument. The position measuring device used for this purpose may be of a variety of constructions; for example, it may include optical cameras, infrared cameras and/or electromagnetic detectors that are capable of determining the three-dimensional position of corresponding markers, for example, optical light-emitting diodes, infrared diodes or electromagnetic transmitters.

[0008] The further versions disclosed in the claims **3** to **5** represent further possibilities for determining the spatial correlation between the X-ray image and the three-dimensional image data set. To this end, the overall three-dimensional image data set, or one or more sub-volumes or individual objects or structures that are particularly prominent in the image data set or individual voxels of the image data set are compared with the X-ray image or searched in the X-ray image. This operation is preferably performed iteratively. Such an advantageous method of comparison is indicated in claim **5** and known from EP 880 109 A2 whereto reference is made explicitly herein and whose disclosure is considered to be included in the present application. Pseudo-projection images are thus formed from the three-dimensional image data set and compared with the X-ray image, the parameters underlying the formation of the pseudo-projection image, for example the imaging scale, projection direction etc., being iteratively varied until the pseudo-projection image and the X-ray image match as well as possible. The spatial correlation between the X-ray image and the 3D image data set is thus found.

[0009] In conformity with claim **6** the method is configured so that it can be executed intra-operatively and continuously, and hence it can serve as a navigational tool for the physician during the treatment of a patient and can continuously deliver instantaneous information concerning the anatomy and the position of the medical instrument.

[0010] In conformity with the advantageous further version disclosed in claim **7**, the three-dimensional image data set is used to derive an image in which the position of the medical instrument or the instrument itself is reproduced.

This also serves as to aid the attending physician during an operation. Different images can then be formed, for example, layer images or projection images that were formed from the three-dimensional image data set and cannot be formed by means of the intra-operatively used X-ray device, for example, combination images from pre-operatively acquired and intra-operatively acquired image data, vascular systems or pre-operatively determined navigation plans.

[0011] The version disclosed in claim **8** is particularly advantageous in that the three-dimensional image data set is acquired pre-operatively by means of an arbitrary imaging device and an X-ray fluoroscopy device, for example a C-arm X-ray device, is used intra-operatively. As a result, images from different imaging modalities and with a different information contents can thus also be intra-operatively presented to the physician during the treatment.

[0012] A device according to the invention which is suitable for carrying out the described method particularly advantageously and includes an X-ray device, a position measuring device and an arithmetic unit is disclosed in claim **9**.

[0013] The invention will be described in detail hereinafter with reference to the drawings. Therein:

[0014] **FIG. 1** shows diagrammatically a device according to the invention,

[0015] **FIG. 2** shows a diagram illustrating the execution of the method, and

[0016] **FIG. 3** shows a block diagram illustrating the method according to the invention.

[0017] **FIG. 1** shows a computed tomography apparatus **1** which is employed to form a series of computer tomograms of a patient **3** prior to a surgical intervention, said tomograms representing parallel slices which extend perpendicularly to the longitudinal axis of the patient. Such computer tomograms form a three-dimensional image data set for a three-dimensional reproduction of the examination zone of the patient **3**. The surgical intervention to be performed at a later stage, for example, can be accurately planned on the basis of such an image data set.

[0018] During the invention two-dimensional X-ray images of the patient **3** on a surgical table **4** are continuously acquired by means of an X-ray device **2**. To this end, a C-arm X-ray device is used in the present case; this device includes an X-ray source **6** and an X-ray detector **7** which are mounted on a C-arm which is supported by a stand **8** (not shown). The C-arm is pivotable about a horizontal axis at least in the direction of an arrow **9**. The X-ray image detection device **7** outputs its output signals, via an analog-to-digital converter **11**, to an image memory **12** which is connected to an arithmetic unit **20**. The X-ray device **2** is controlled by means of a control unit **10**.

[0019] Also provided is a position measuring device **13** with two infrared CCD cameras **14** which are arranged on a stand to the side of the examination zone. The spatial positions of correspondingly constructed infrared light-emitting diodes can be determined by means of said cameras. In order to determine the position of a medical instrument **16** used during the intervention, in this case being a biopsy needle, the end of the biopsy needle **16** which projects from the patient is provided with three of such infrared light-emitting diodes **17** in defined positions. In order to determine the position of the X-ray device **2**, or the imaging geometry of the X-ray device **2**, during the acquisition of X-ray images during the operation, three of such light-emitting diodes **18** and **19**, respectively, are provided on the X-ray source **6** and the X-ray detector **7**, respectively. The spatial position of an acquired X-ray image can be determined from the imaging geometry thus determined, that is, the position of the X-ray image relative to the patient **3**. This calculation and the storage of the positions determined take place in a position calculation unit **15** whose results are applied to the arithmetic unit **20**.

[0020] The arithmetic unit **20** receives not only the intra-operatively acquired X-ray images and the measured positions, but also the image data set pre-operatively acquired by the computed tomography apparatus **1**. From such data it determines the spatial correlation between the two-dimensional X-ray image and the three-dimensional image data set by means of a comparison method yet to be explained. After determination of this correlation rule, the spatial position of the medical instrument **16** can be transformed into a position relative to the three-dimensional image data set and one or more images can be formed from the three-dimensional image data set and/or the intra-operatively acquired X-ray image, which images can be displayed on a monitor **21** and the position of the medical instrument can be reproduced therein.

[0021] **FIG. 2** again shows the individual steps of the method in the form of a flow chart. During the pre-operatively executed step **101** a three-dimensional image data set CT is acquired by means of the computed tomography apparatus; this image data set is a three-dimensional representation of the absorption distribution within a volume to be examined. From this volume there may also be selected a sub-volume CTP which region a region of particular interest for the later intervention. This selection can be performed manually or also automatically by segmentation.

[0022] The intra-operatively executed subsequent steps **102** to **104** can be carried out continuously or repeatedly with desired time intervals or at given instants during an intervention. During the step **102** a two-dimensional X-ray image I_r and the positions of the imaging geometry and of the medical instrument are determined simultaneously. Subsequently, in the step **103** the correlation rule between the X-ray image I_r and the overall volume CT, or the sub-volume CT_p, of the three-dimensional image data set is determined.

[0023] Finally, in the step **104** this rule is used to determine the position of the medical instrument in the overall volume CT or the sub-volume CT_p of the image data set and possibly to form suitable images.

[0024] The comparison method for determining the correlation rule will be described in detail hereinafter with reference to **FIG. 3**. The three-dimensional image data set CT is formed from a plurality of layer images CT1, CT2, . . . , CTX acquired by the computed tomography apparatus. From this set there is selected a sub-volume CT_p which is relevant to the later intervention and represents, for example, a vertebra in the case shown.

[0025] The spatial transformation or correlation between the image of the patient, notably of the segmented vertebra, represented by the CT data set and the spatial position of this vertebra is determined by means of the intra-operatively acquired X-ray image I_r. To this end, pseudo-projection

images I_p are formed of the sub-volume CT_p. The magnitude of the pseudo-projection image I_p should correspond to that of the X-ray image I_r. The position of the projection point wherefrom projection takes place from the sub-volume CT_p to the pseudo-projection image I_p corresponds to the position of the X-ray source (or the focal spot of the X-ray source emitting the X-rays) in relation to the X-ray detector during the X-ray exposure. Generally speaking, the starting position of the sub-volume CT_p initially selected in relation to the projection point and the projection direction do not correspond to the position and the orientation of the real sub-volume in relation to the X-ray source and the X-ray detector during the acquisition of the X-ray image. Therefore, these projection parameters of the sub-volume CT_p are varied in relation to the projection point and the plane of the projection image I_p until a difference image I_d, derived from the difference between the X-ray image I_r and the pseudo-projection image I_p, produces an as good as possible image of the vertebra CT_p. This is the case when the position and orientation of the vertebra CT_p on which the pseudo-projection image I_p is based correspond to the position and the orientation of the real vertebra in relation to the X-ray source and the X-ray detector. For a further explanation of this method reference is again made to the cited EP 880 109 A2.

[0026] The described method enables very accurate determination of the correlation between the X-ray image I_r and the three-dimensional image data set CT in the two directions perpendicular to the direction of the X-ray beam. Such a determination, however, is substantially less accurate in the direction of the central beam. This situation, however, can be improved by forming a second X-ray image with a beam path extending perpendicularly to that used for the first X-ray image and by carrying out the comparison method also by means of this second X-ray image.

[0027] The invention is not limited to the embodiment shown which is given merely by way of example. The three-dimensional image data set can also be acquired by means of a different imaging system; moreover, the intra-operatively used X-ray device and the position measuring device may also have a different construction for as long as the necessary functionality is provided. The exact configuration of the steps of the method, notably the determination of the correlation rule between the three-dimensional image data set and the two-dimensional X-ray images may also be completely different. The described comparison method is given merely as an example of the determination of such a correlation.

1. A method of determining the position of a medical instrument **(13)**, partly introduced into an object **(3)** to be examined, in a three-dimensional image data set (CT) of the object **(3)** to be examined, which method includes the following steps:

acquisition of a two-dimensional X-ray image (I_r) of the object **(3)** to be examined by means of an X-ray device **(2)**,

determination of the spatial positions of the X-ray image (I_r) and the medical instrument **(16)**,

determination of the spatial correlation between the X-ray image (I_r) and the three-dimensional image data set (CT), and

determination of the position of the medical instrument **(16)** in the three-dimensional image data set (CT) from the spatial position of the medical instrument **(16)** on the basis of the spatial correlation between the X-ray image (I_r) and the three-dimensional image data set (CT).

2. A method as claimed in claim 1, characterized in that the spatial position in space of the X-ray image (I_r) is determined in that the spatial positions of the imaging elements **(6, 7)** of the X-ray device **(2)**, notably of the X-ray source **(6)** and the X-ray detector **(7)**, are determined by means of a position measuring device **(13)**.

3. A method as claimed in claim 1, characterized in that the spatial correlation between the X-ray image (I_r) and the three-dimensional image data set (CT) is determined by means of a comparison method.

4. A method as claimed in claim 3, characterized in that in conformity with the comparison method a sub-volume (CT_p) of the three-dimensional image data set (CT) is compared with the X-ray image and a correlation rule is determined iteratively.

5. A method as claimed in claim 3 or 4, characterized in that in conformity with the comparison method a pseudo-projection image (I_p) is determined from at least a data sub-set (CT_p) of the three-dimensional image data set (CT), the pseudo-projection image (I_p) is compared with the X-ray image (I_r), and the parameters underlying the determination of the pseudo-projection image (I_p) are iteratively varied until optimum correspondence is achieved between the pseudo-projection image (I_p) and the X-ray image (I_r).

6. A method as claimed in claim 1, characterized in that the method is performed intra-operatively and continuously.

7. A method as claimed in claim 1, characterized in that an image formed from the three-dimensional image data set (CT) is displayed and the position of the medical instrument **(16)** or the instrument **(16)** itself is reproduced in said image.

8. A method as claimed in claim 1, characterized in that the X-ray image (I_r) is acquired by means of an X-ray fluoroscopy device **(2)** and that the three-dimensional image data set (CT) is acquired in a pre-operative manner by means of a computed tomography apparatus **(1)**, a magnetic resonance tomography apparatus, an ultrasound device or an X-ray device.

9. A device for determining the position of a medical instrument **(16)**, introduced into an object **(3)** to be examined, in a three-dimensional image data set (CT) of the object **(3)** to be examined, which device includes:

an X-ray device **(2)** for the acquisition of a two-dimensional X-ray image (I_r) of the object **(3)** to be examined,

a position measuring device **(13)** for measuring the spatial positions of the X-ray image (I_r) and of the medical instrument **(16)**, and

an arithmetic unit **(20)** for determining the spatial correlation between the X-ray image (I_r) and the three-dimensional image data set (CT), and for determining the position of the medical instrument **(16)** in the three-dimensional image data set (CT) from the spatial position of the medical instrument **(16)** by means of the spatial correlation between the X-ray image (I_r) and the three-dimensional image data set (CT).

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